Evolution modeling of stakeholder performance on relationship management in the dynamic and complex environments of megaprojects

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ABSTRACT

Purpose (limit 100 words): Relationship management evolves with dynamic and complex environments of megaprojects. However, studies on the longitudinal measurement of relationship management performance for each stakeholder in dynamic and complex project environments are lacking. The purpose of this research is to propose an NK–Network evolution model to evaluate stakeholder performance on relationship management in the development of megaprojects.

Design/methodology/approach (limit 100 words): The model input includes the stakeholder-associated issues

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and stakeholders' relational strategies, the co-effects of which determine the internal effects of relationship management in megaprojects. The model processing simulates the stakeholder performance of relationship management under the dynamic and complex nature of megaprojects. The NK model shows the dynamic stakeholder interactions on relationship management, whereas the network model presents the complex stakeholder structures of the relationships between stakeholders and relevant issues. The model output is the evolution graph to reveal the weak stakeholder performance on relationship management in the timeline of the project duration.

Findings (limit 100 words): The research finding reveals that all stakeholders experience the plunge of stakeholder performance of relationship management at the decision-making moment of the planning stage. Construction, environmental, and pressure groups may experience the hardship of relationship management at the start of the construction stage. The government is likely to suffer difficulties in relationship management in the late construction stage. Local industry groups would face challenges in relationship management in the middle of the construction stage and handover stage.

Originality/value (limit 100 words): The research provides a useful approach to measuring weak moments of relationship management for each stakeholder in various project phases, considering the dynamic and complex environments of megaprojects. The proposed model extends the current knowledge body on how to make project stakeholder analysis by modelling dynamic and complex environments of megaprojects, with bridging the knowledge domains of evolution modeling techniques and network methods.

Keyword: Relationship management; Stakeholder; Evolution modeling; Megaprojects

Introduction

Relationship management (RM) in megaprojects is defined as a way to establish a cooperative environment among project stakeholders by adopting managerial strategies and processes to achieve good project performance (Zou et al., 2014, Pryke and Smyth, 2012, Cheung and Rowlinson, 2011, Zheng et al., 2017). The megaprojects involve various kinds of project stakeholders. On the one hand, the internal stakeholder groups directly participate in the project execution, including the government departments and construction groups (Ujene and Edike, 2015). On the other hand, the external stakeholder groups are affected by the project development, such as the environmental groups, local community groups, and local industry groups (Olander and Landin, 2008, Benn et al., 2009). The involvement of internal and external stakeholders with diverse interests triggers tensions in various phases of megaprojects, which calls for effective RM for stakeholder relationships. (Shen and Xue, 2021, Turkulainen et al., 2015, Do et al., 2021). For instance, in the planning stage, the tension caused by conflicting economic interests among stakeholders may cause a project to become defunded (Zafar et al., 2019). In the construction stage, conflicts arising from the environmental impact assessment between local communities and official departments cause the delay and cost overrun of a project (Xue et al., 2020b). In the handover stage, the dispute of operational arrangements is difficult to avoid among stakeholders, thus exerting pressure on the smooth operation of a project (Xue et al., 2020b). Therefore, it is essential for stakeholders to understand the evolution of RM performance in megaprojects, which is helpful to propose RM strategies in each phase for improving project performance (Meng, 2012).

RM of stakeholders is evolved with dynamic and complex project environments in megaprojects (Shen and Xue, 2021, Kardes et al., 2013, Flyvbjerg, 2014). The dynamic environment of RM is led by stakeholder dynamics, in which RM strategies are influenced and vary by frequent stakeholder interactions in various timepoints of long-term project duration (Shen and Xue, 2021, Aaltonen et al., 2015). The complex environment of RM is caused by stakeholder complexities, in which the interdependent stakeholders and their concerned issues form the complex stakeholder structures (Mok et al., 2017b). The complex stakeholder structures shape the complicated stakeholder relationships for RM in megaprojects (Mok et al., 2015, Xue et al., 2020c). The previous studies have shown RM evaluation approaches from dynamic and complex perspectives, respectively. However, it still lacks the research on stakeholder evolution of RM considering both dynamic and complex environments of megaprojects. In terms of RM in the dynamic environment, the NK model, as an organizational simulation approach of the complex adaptive system, can evaluate the evolution of stakeholder interactions in the RM decision-making process under the dynamic environment (Ganco, 2017, Rivkin and Siggelkow, 2002). While in the aspect of RM in the complex environment, the Network model, as an effective tool to analyze the complexities of interrelated organizations, can measure the risks of stakeholder relationships and facilitate RM in complex projects (Luo et al., 2019, Yang et al., 2016). As the NK and Network models have been proved to solve RM problems separately, it is promising to integrate two models as an NK-Network model to assess stakeholder evolution of RM performance under the dynamic and complex nature of megaprojects.

Hong Kong-Zhuhai-Macao Bridge is the longest sea-crossing megaprojects (55 kilometers) in the world, connecting the major cities in the prosperous Great Bay Area in Southern China. It costs the US $18.8 billion with cost overruns and schedule delays due to the dynamic and complex project environments. On the one hand, there are various kinds of stakeholders in the project, including the government, construction groups, local communities, environmental groups, and local industry groups. As the project takes the Design-build procurement mode, the construction groups refer to the combination of contractors, designers, subcontractors, and workers, undertaking the construction and design works. The stakeholder groups with divergent interests face the RM challenges of various project issues, triggering the stakeholder complexities. On the other hand, the project duration lasts for 16 years (2003-2018). The long-term project duration leads to dynamic interactions among stakeholder groups, causing confrontations among stakeholders in aspects of cost, schedule, safety, environment, and etc. Therefore, the case of HZMB provides a project setting with both dynamic and complex environments to validate the proposed evolution model for the evaluation of stakeholder performance on RM in megaprojects.

In this study, an NK–Network model was established to evaluate the evolution of stakeholder performance on RM in megaprojects. The proposed model considers stakeholder dynamics and complexities in megaprojects. On the one hand, the NK model simulates the dynamic stakeholder interactions in RM toward stakeholder-associated issues. On the other hand, the Network model presents the complex stakeholder structures between stakeholders and their associated issues in megaprojects. With the simulative model, the evolution of stakeholder performance on RM is measured in the timeline, which is useful to detect the weak moments of RM for each stakeholder. Model validation was conducted using the famous megaproject of the Hong Kong–Zhuhai–Macao Bridge (HZMB) in the Great Bay Area of China. The simulative results were furtherly verified and interpreted with the development history of HZMB.

Background

Relationship management in megaprojects

Relationship management is essential for project success by enhancing stakeholder collaborations (Jelodar et al., 2016, Meng, 2012). RM was introduced as an innovative management theory to explain the shift of project management from traditional paradigm to relational paradigm (Pryke and Smyth, 2012). However, the previous study also indicates managing complicated relationships among stakeholders in megaprojects is challenging and waiting for more in-depth research (Mok et al., 2015, Xue et al., 2020c). RM is relevant to various project aspects, including the procurement types, project size, cost, and types. In the aspect of procurement types, the project procurement system influences the relationship structure among involved stakeholders (Smyth and Edkins, 2007). For instance, the RM studies on Public-Private Partnership projects are focused on the relationship between private organizations and public clients (Zou et al., 2014). The RM for Engineering Procurement Construction projects is around the coordination between main contractors, subcontractors, and suppliers (Pal et al., 2017). Besides, the RM in conventional Design-Bid-Build projects deals with the relationship among the owner, contractors, and consultants (Pal et al., 2017). In terms of project cost, the megaprojects have a huge volume of investment with over 1 billion US dollars (Flyvbjerg, 2014). The high project cost leads to a significant social impact, attracting the attention of external stakeholders (i.e., local communities and industry groups) (Jia et al., 2011). Hence, the RM in megaprojects is crucial for keeping a collaborative relationship between internal stakeholders (i.e., contractors, subcontractors, suppliers, and consultants) and external stakeholders (i.e., local communities and industry groups) (Xue et al., 2020c). The megaprojects have a huge size which takes a long-term project duration from planning to handover (Ma et al., 2017). The mega-size involves various planned and unexpected project issues that occurred in different stages of a megaproject, including cost overruns, schedule delays, safety incidents, quality defects, environmental conflicts, and etc. (Kardes et al., 2013). The project issues activate the conflicting and interdependent concerns and interests among stakeholders, leading to the complex environment of RM (Mok et al., 2017b). There are different megaproject types, such as transport systems, energy facilities, buildings, dams, harbors, many of which are fully or partially funded by the government (Zhou and Mi, 2017). As the type of public-funded project, RM in megaprojects pays special attention to the relationship between the government and the public

(Wu et al., 2019). The two key stakeholders have dynamic interactions in the whole project development, causing conflicts in a wide range of public issues relevant to the project, including environmental assessment, budget plan, and urban development in project neighboring areas (Xue et al., 2020b). Thus, the frequent interactions between the government and public reflect the dynamic environment of RM.

In summary, RM in megaprojects is deeply involved by stakeholders under dynamic and complex environments. As the megaprojects have a long-term project duration, dynamic RM is critical for stakeholders to manage their relationships in each project phase (Mazur et al., 2014). Dynamic RM is defined as a capability to achieve RM in a changeable environment (Lemon et al., 2002). Understanding the changeable performance of RM is beneficial for stakeholders to achieve dynamic RM (Zou et al., 2014) because the dynamic RM strategies can be proposed for stakeholders to enhance the weak moments of RM in the development of megaprojects.

Stakeholder performance of relationship management

The measurement of stakeholder performance is useful in understanding the weak moments of RM for each stakeholder in megaprojects (Roumboutsos et al., 2013). The stakeholder performance of RM is determined by the internal effects and external environments of megaprojects. On the one hand, RM performance is co-affected by the stakeholder-associated issues and stakeholders' relational strategies. RM is deeply influenced by various stakeholder-associated issues (Mok et al., 2017b). The stakeholder-associated issues refer to the events concerned among stakeholders (Li et al., 2012). The issues reflect the various concerns and interests of stakeholders, which leads to interactive stakeholder relationships in the megaprojects (Xue et al., 2020b). To deal with the interdependent stakeholder relationships, the previous study indicates that stakeholder relationships could be improved by the enhancement of formal and informal relationships in megaprojects

(Xue et al., 2020a). Formal relationships strengthen stakeholder connections by legal contracts and codified documents, whereas informal relationships establish intimate relations to make stakeholder links smooth (Poppo and Zenger, 2002, Prell et al., 2010). Therefore, the formal and informal relational strategies are essential to improve stakeholder collaborations to tackle the conflicting stakeholder-associated issues in megaprojects.

On the other hand, RM faces challenging external environments of megaprojects. Compared to traditional construction projects, megaprojects have more dynamic and complex project environments (Flyvbjerg, 2014). In the aspect of dynamics, the long-term project duration leads to dynamic stakeholder interactions in megaprojects (Aaltonen et al., 2015). As frequent stakeholder interactions around the stakeholder-associated issues, each stakeholder's RM performance is varied (Shen and Xue, 2021). The dynamic stakeholder interactions cause the changeable RM performance since one stakeholder's behavior adjustment would influence other stakeholders' RM strategies (Westhoff et al., 1996, Weaver, 2007, Co and Barro, 2009). In terms of complexity, the stakeholder structure is complicated in megaprojects due to the wide interrelations between stakeholders and stakeholder-associated issues (Mok et al., 2017b, Mok et al., 2017a). The complex stakeholder structures present difficulties on RM as a vast number of conflicting benefits and interests among stakeholders (Yang and Shen, 2014).

Besides internal effects and external environments, the stakeholder performance of RM is required to consider the various project phases. The longer project period exerts heavier pressure on RM in megaprojects (Shen and Xue, 2021). Thus, the evolution of RM performance is assessed from the start to the end of megaprojects in order to provide effective strategies on RM for stakeholders in the project development. In summary, the conceptual model of stakeholder performance of RM in megaprojects is shown in Figure 1.

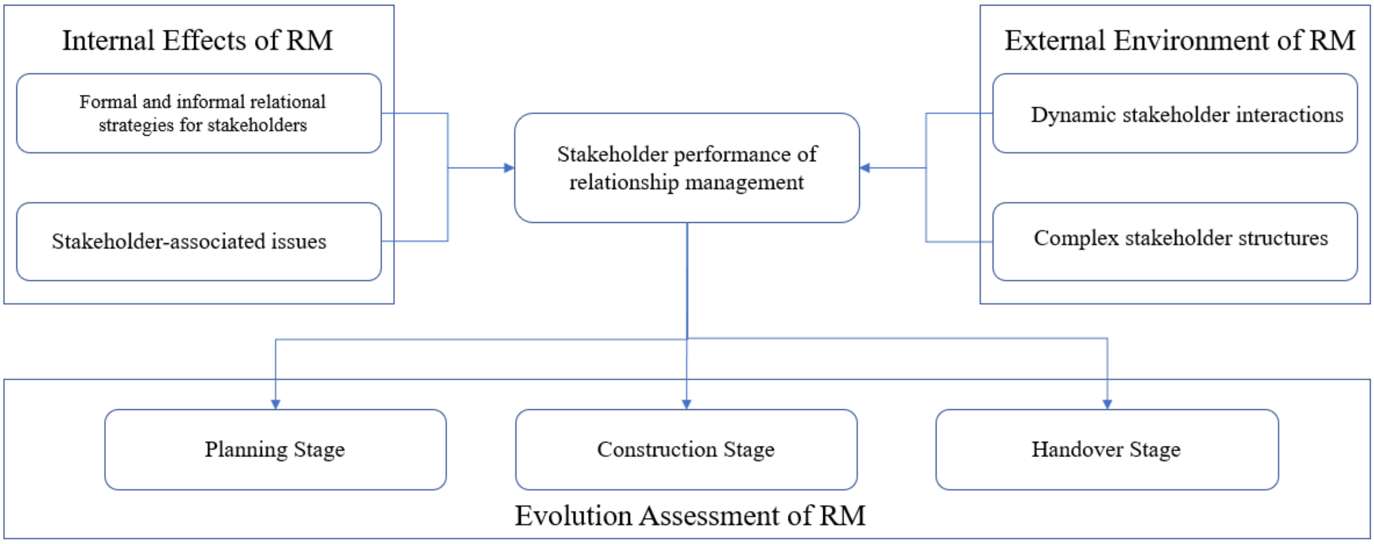


Figure 1 Conceptual model of stakeholder performance of relationship management

Evolution modeling techniques

NK modeling was a classical evolution modeling technique developed from the concept of the fitness landscape, which was proposed by Wright (1932). The fitness landscape was presented to show the biological evolution by assigning adaptive values from the mathematical distribution under a set of gene combinations. In 1987, the NK model was proposed by Kauffman and Levin (1987)on the basis of the fitness landscape. The model describes the adaptive walks of a group of gene combinations to explore evolutionary strategies. NK modeling was brought into the domain of organization and management science in the 1990s (Kauffman, 1993, Levinthal, 1997). The simulation model shows how the complexity of organizations affects the performance of the system (Ganco, 2017), the strength of which is providing a method to address the problems of organizational complexity that are difficult to answer empirically (Ganco and Hoetker, 2009). Later, the NK modeling was proven to be effective in studying the adaptive complex system (Capaldo and Giannoccaro, 2015), which is a system combined with the features of dynamics and complexity. The complex adaptive system is composed of networks of adaptive agents that continuously interact with one other over time (Holland, 1995). The NK model combined with the Network model is useful in discussing the strategic works in complex adaptive systems with computational simulations (Pascale et al., 1999). Compared with the model of system dynamics and agent-based modeling, the NK modeling approach is competitive on the simulation of the coevolutionary complex system arising from the number of elements (*N*) and the dynamic interactions among them (*K*) (Giannoccaro et al., 2018). The model has been applied to understand the evolution mechanism of organizations under dynamic and complex environments. For instance, the NK simulation model helps organizations find the best position in a dynamic environment (Gavetti et al., 2005), assists researchers in understanding the fit between dynamic organizational interactions and environment (Barr and Hanaki, 2008), and analyzes the interdependence relationship of overall complex supply chain networks (Capaldo and Giannoccaro, 2015). In megaprojects, stakeholders with various interests frequently communicate and coordinate with each other to achieve project goals and maximize their own benefits in the project duration (Mok et al., 2015, Xue et al., 2020a). This interaction is similar to a network of interacting agents who seek the better organizational performance by adaptive walks in the fitness landscape (Holland, 1995, Levinthal, 1997). As an efficient method for the adaptive complex system, NK model has the potential to work with the Network model in studying stakeholder performance with dynamic stakeholder interactions and complex stakeholder structures of megaprojects.

Model design

Framework of the NK–Network model

Figure 2 shows that the proposed NK–Network evolution model is based on the conceptual model (in Figure 1) of stakeholder performance in RM, which is composed of three parts: input, processing, and output. The input model shows the internal effects of RM. Input one is the two-mode stakeholder–issue networks, which explicitly present the complicated relationship structure with stakeholders and their associated issues in various stages of megaprojects. Input two is the performance distribution of relational strategies toward each type of stakeholder issue, which reflects the effectiveness of the relational strategy for each stakeholder to improve RM in the development of megaprojects. The processing modular reflects how the internal effects of RM co-effect with the external environment of megaprojects. The proposed NK–Network model simulates the stakeholder performance considering the dynamics and complexity of megaprojects. The NK model simulates the dynamic stakeholder interactions in the decision-making of relational strategies to boost RM in the project duration. The Network model represents the complex stakeholder structures between stakeholders and relevant issues that exert influence on stakeholder relationships in megaprojects. The output is the stakeholder evolution graph, which shows the evolution assessment result of stakeholder performance on RM in each time point of a megaproject.

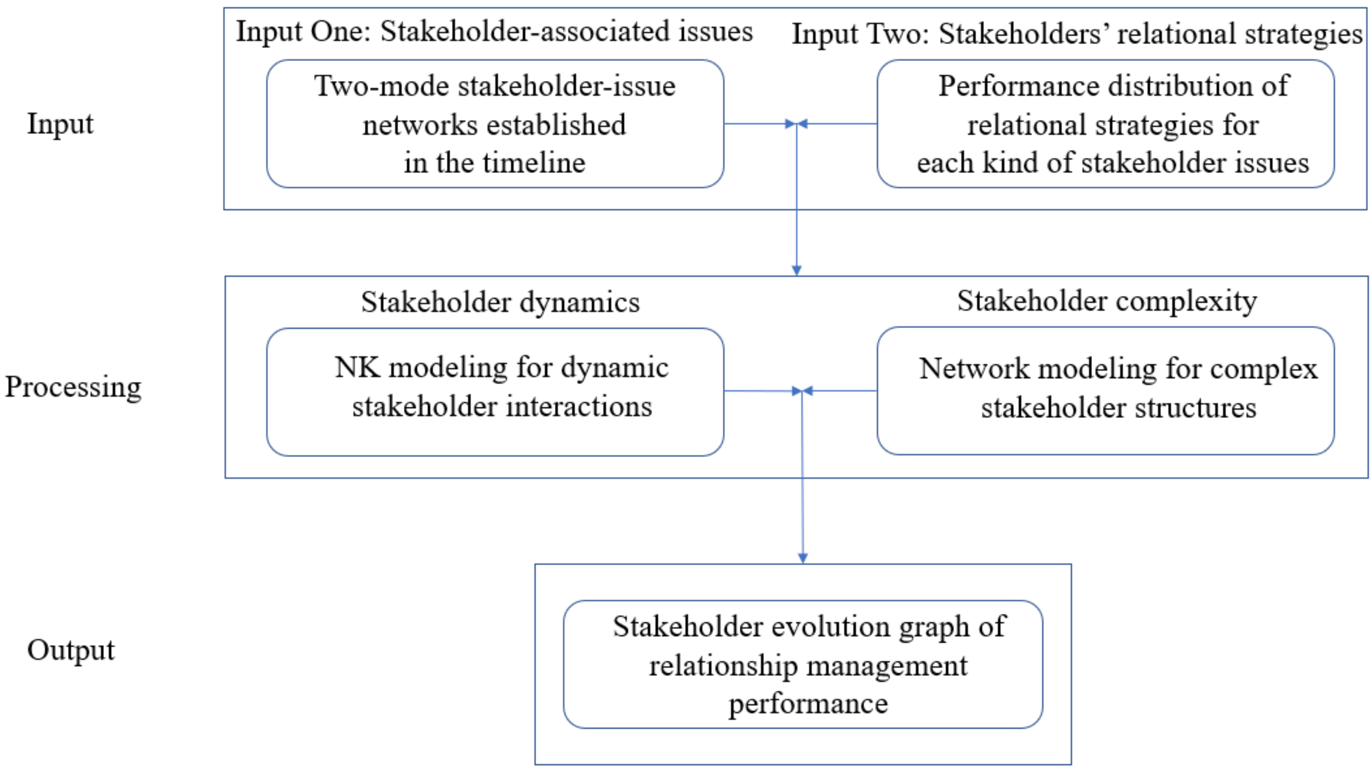


Figure 2 Framework of the NK–Network evolution model

Input One: Stakeholder-associated issues

The previous study shows that stakeholder relationship is significantly influenced by changeable, relevant stakeholder issues in megaprojects (Mok et al., 2017b). Thus, the two-mode network of stakeholder issues is established to reflect the complexity of the relationship structure for stakeholder RM. The two-mode stakeholder–issue network has two components. One mode is the stakeholders, and the other is the stakeholder-associated issues; both components show two elements of stakeholder interactions. The link represents the stakeholder involved in a corresponding issue in project duration. The two-mode Network model comprehensively reflects the complicated relationship between stakeholders and their relevant issues, which serves as the basis of the simulation analysis of stakeholder interactions.

Input Two: Stakeholder relational strategies

Stakeholder relational strategy refers to stakeholder efforts that improve RM in each stakeholder issue. On the basis of stakeholder RM in megaprojects, two critical enhancement relational strategies face stakeholder issues (Yang and Shen, 2014). One is the formal relational strategy, and the other is the informal relational strategy (Xue et al., 2020a). To understand the performance of each relational strategy, a performance distribution of each strategy under various kinds of stakeholder issues needs to be assessed. The performance distribution presents the general scope of stakeholder performance values under each strategy, which is useful to simulate the stakeholder performance of RM. The performance distribution of relational strategies can be obtained from two sources. One is from previous empirical studies that have performed the similar evaluation. The effects of formal and informal relational strategies toward various stakeholder issues in megaprojects were examined by Xue et al. (2020a) from the organizational level to the project and societal level. The empirical results serve as the reference to form the normal distribution of stakeholder performance values under the formal or informal relational strategy. Wide-range surveys among experts and professionals serve as another source. Survey results could be used to fit the performance distribution of formal and informal relational strategies for each type of stakeholder issue. Finally, stakeholder performance value distribution P_i is obtained for each stakeholder strategy D_i.

Process: NK–Network modeling for stakeholder dynamics and complexity

NK parameter

As two critical parameters in the NK model, *N* represents the number of project stakeholders, whereas *K* refers to the complexity of project stakeholders. As Figure 3 shows, toward a specific stakeholder issue C_i derived from Input One, *N* stands for the number of stakeholders related to the issue C_i, whereas *K* is equivalent to *N*−1 as each involved stakeholder behavior would be influenced by other stakeholders associated with the same issue.

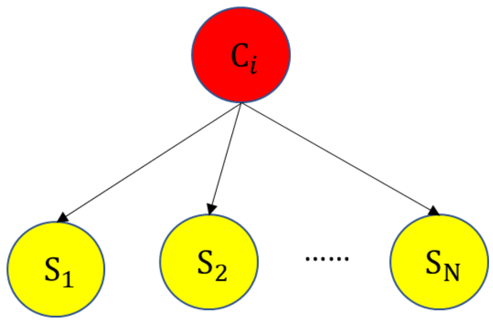


Figure 3 Basic NK model for one stakeholder-issue

Performance Landscape

The performance landscape is generated according to the stakeholder performance of RM on each kind of issue (Kauffman, 1993). For a specific issue C_i, each relevant stakeholder would determine its relational strategy d_i to improve the RM. Therefore, it generates a decision vector D for a specific issue C_i as follows.

$$D = (d_1, d_2, \dots, d_N), d_i \in \{1 = formal\ relational\ strategy, 0 = informal\ relational\ strategy\}$$

For each specific d_i, the enhancement decision leads to a pay-off value to measure the stakeholder performance under this decision. Correspondingly, a pay-off vector is generated as $P = (P_1, P_2, \dots, P_N)$. The value of P is derived from Input Two, which draws the performance distribution of each stakeholder relational strategy. Considered the NK model as a system, the system's stakeholder performance value $P(D)$ under a specific decision vector D is $P(D) = (\sum_{i=1}^{N} P_i)/N$.

To generate the performance landscape of a specific issue C, it is randomly generated from all the combinations of decision vector D and their corresponding pay-off vectors P and system's stakeholder performance values $P(D)$. The performance landscape of specific issue C is composed of all the combinations of D, P, and $P(D)$.

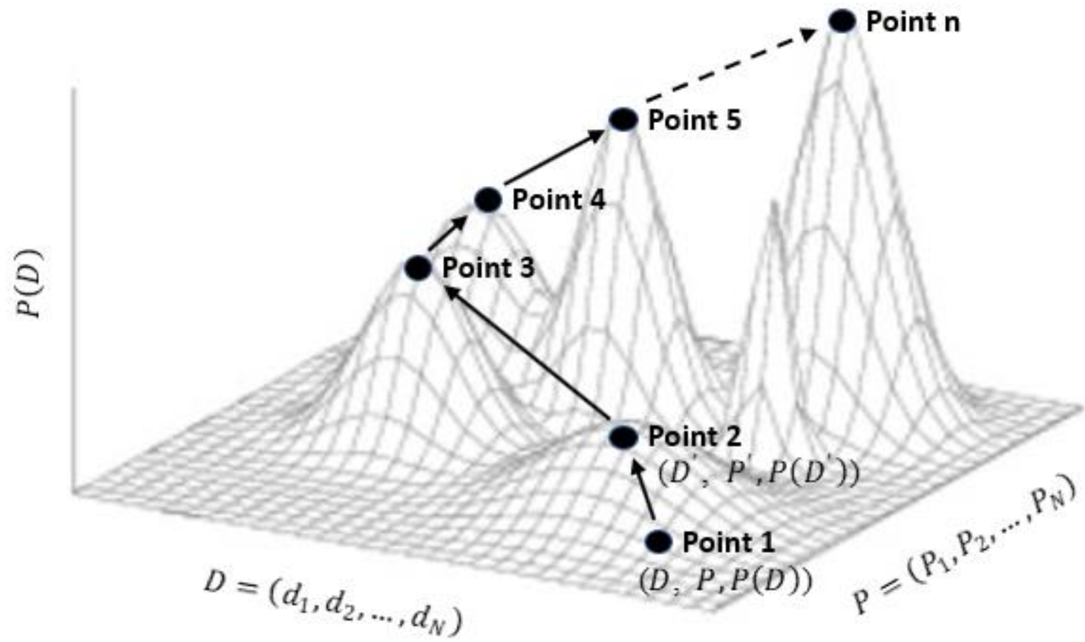


Figure 4 The performance landscape of the NK model

Simulation of stakeholder dynamics by NK modeling

Stakeholder dynamics reflect how stakeholders switch their relational strategies for improving their RM performance, under environment of dynamic stakeholder interactions (Rivkin and Siggelkow, 2002). For a specific stakeholder issue, each stakeholder's decision on enhancement strategies is influenced by other stakeholders associated with the same issue. For instance, when one stakeholder changes the strategy (d_1->d_1'), other stakeholders adjust their solutions simultaneously due to their interactive influence (d_2->d_2', d_3->d_3', ..., d_N->d_N'). As a result, the stakeholder-issue's decision vector is changed from $D =$

$(d_1, d_2, \ldots, d_N)$ to $D' = (d'_1, d'_2, \ldots, d'_N)$, which represents the move from one point $(D,\ P, P(D))$ to another point $(D',\ P', P(D'))$ on the performance landscape (shown in Figure 4). Meanwhile, each stakeholder decides its enhancement strategy based on the evaluation of benefits and costs. The stakeholder chooses to change its strategy when the switch leads to the improvement of RM performance. Therefore, the system's stakeholder performance value $P(D)$ gradually increases on the landscape after each round of the decision vector changes (shown in Figure 4). It reflects the dynamic nature of stakeholder behaviors in seeking for better RM performance through frequent stakeholder interactions in megaprojects. Finally, the move would stop on the one point that no matter how stakeholders change their enhancement strategies that would not further improve the RM performance anymore, which means the stakeholders have tried their best on realizing RM around the stakeholder-issue.

In the NK model, the search method function is used to seek for the final status of stakeholder interactions on RM in the dynamic environment of megaprojects. The search method is based on the local search modular, which is popular in exploring the final status of agents on the performance landscape (Ganco, 2017, Sommer and Loch, 2004). The principle of the local search is to switch elements in decision vector D to explore the best system's stakeholder performance value P(D). Iterations are made until the value cannot be improved, which means the enhancement decision combination among stakeholders has reached a final status after dynamic stakeholder interactions (Ganco, 2017).

According to the local search, two basic search methods reflect the stakeholder collaborations faced with the common stakeholder issue: planning and learning (Weaver, 2007). The first method is called the "planning" strategy, which assumes that each stakeholder in the NK model would seek collaborations and accept the compromising arrangement with the aim to achieve the overall best RM performance that tackles the common stakeholder issue. When the search is initiated:

If $P(D_{n+1})>P(D_n)$:

$$D_n = D_{n+1}$$

$$P(D_n) = P(D_{n+1})$$

The second method is called the “learning” strategy, which assumes that each stakeholder in the NK model would only seek the solution to improve its own performance to tackle the issue. In the “learning” strategy, each project organization would learn how to address an issue with the primary aim of improving its own RM performance. Thus, when the search is initiated:

As decision vector D under n iterations $D_n = (d_n^1, d_n^2, \dots, d_n^N)$, the corresponding pay-off vector is $P_n = (P_n^1, P_n^2, \dots, P_n^N)$,

If each $P_{n+1}^i>P_n^i$, $i \in [1, \mathrm{N}]$:

$$D_n = D_{n+1}$$

$$P(D_n) = P(D_{n+1})$$

In fact, “planning” and “learning” strategies occur in reality. On the one hand, with the common aim to complete a successful project, some internal stakeholder groups (contractor, consultant, subcontractor) follow the “planning strategy,” as they can make a compromise to achieve the best performance of the system (Ujene and Edike, 2015). On the other hand, considering the mainstream opposition forces, some stakeholder groups (local community, environmental group) follow the “learning strategy,” as they only focus on the improvement of their own interests (Olander and Landin, 2008, Xue et al., 2020a). Therefore, the third search method that combines the “planning” and “learning” strategies is proposed.

For a specific issue, the stakeholder group who follows the “learning” strategy focuses on the improvement of its own performance ($P_{n+1}^{i}>P_{n}^{i}$); whereas the stakeholder group who follows the "planning" strategy expects that the overall performance toward the issue could be improved ($P(D_{n+1})> P(D_n)$). Thus, when the search is initiated:

Assume that *j* represents the group of stakeholders who follow a "learning" strategy,

If $P(D_{n+1})> P(D_n)$ and each $P_{n+1}^{i}>P_{n}^{i},\ i \in j$:

$$D_n = D_{n+1}$$

$$P(D_n) = P(D_{n+1})$$

We employ the third search method that combines the "planning" and "learning" strategies. When the search is finished, the final stakeholder performance value of system $P(D)_{final}$ and final pay-off value vector $P = (P^{S_1}, P^{S_2}, \dots, P^{S_k})_{final}$ are obtained. With the final pay-off value vector, the performance score of each stakeholder group S_k in the involved issue could be obtained as $(P^{S_k})_{final}$. $P(D)_{final}$ and $(P^{S_k})_{final}$ are beneficial for decision-makers to understand the final status of RM performance for each stakeholder around one common issue after dynamic stakeholder interactions.

Simulation of stakeholder complexity by Network modeling

Stakeholder complexity is reflected by the complicated stakeholder structure between stakeholder-issues and their associated stakeholders. The two-mode stakeholder–issue network represents the complex stakeholder structure. The network (Figure 5) contains several basic NK models, since one specific stakeholder-issue C_i and relevant stakeholders S_k are considered as one basic NK model.

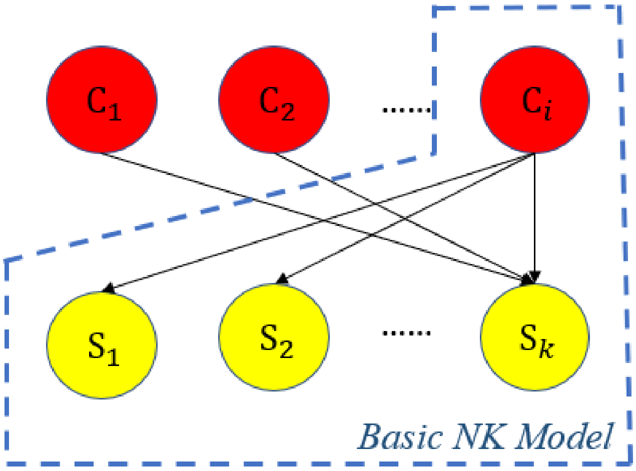


Figure 5 Two-mode stakeholder–issue network

Given that each stakeholder group S_k may join various issues in the network, the performance of S_k should be comprehensively evaluated by the pay-off value in the NK model of each involved issue. Therefore, the performance score of each stakeholder group S_k is determined by the mean of final pay-off values in each of relevant basic NK models. The calculation is as follows:

$$P(S_k) = \frac{\Sigma(P_{C_i}^{S_k})_{final}}{The\ number\ of\ invovled\ issue\ C_i},$$

where $(P_{C_i}^{S_k})_{final}$ means the final pay-off value of stakeholder group S_k under its involved issue C_i, after dynamic stakeholder interactions.

Output: Stakeholder evolution graph

The two-mode stakeholder–issue networks are established in the timeline from the beginning to the end of the megaprojects (shown in Figure 6). Hence, the simulation results of the NK–Network model at each given time point n are revealed. The simulation results assist decision-makers in understanding the variations of stakeholder performance $P_n(S_k)$ on RM toward changeable issues in the project duration.

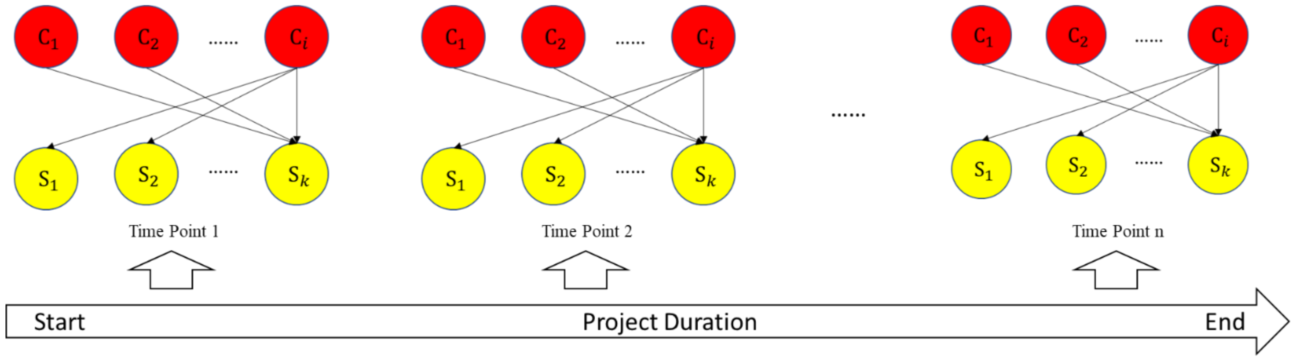


Figure 6 Timestamped stakeholder stakeholder–issue networks

Figure 7 depicts the evolution graph of the stakeholder performance with the timestamped information of each network. The graph shows the trend of stakeholder performance $P_n(S_k)$ in the timeline, indicating the weakness of stakeholder performance on RM in different stages of the megaprojects.

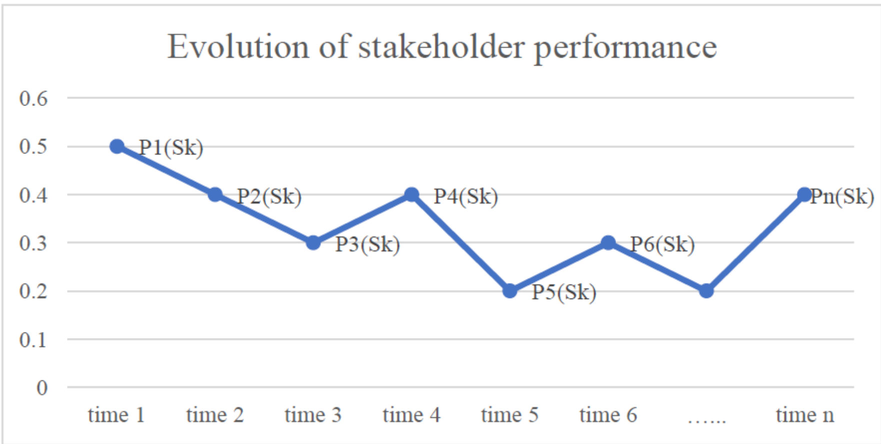


Figure 7 Evolution graph of stakeholder performance

Case validation

As an effective exploratory method, the single instrumental case study was employed to validate the proposed evolution model. The method is suitable to examine the validity of the designed stakeholder analytical tool under a real project environment (Mok et al., 2017c). As the longest sea-crossing bridge system in the world, the HZMB is selected as a megaproject case, with a far-reaching impact on the development of the Guangdong–Hong Kong–Macao Greater Bay Area. The 55-km bridge cost RMB 127 billion and took almost 16 years from the planning (2003–2008) to construction (2009–2017) and handover (2018). The wide range of interacting stakeholder participation triggered a few severe conflicts in RM, causing a negative influence on project performance. Therefore, the proposed model is adopted to evaluate the evolution of stakeholder performance on RM in three different stages of the HZMB. The detected weak moments of stakeholders on RM are checked according to the history of the HZMB, thus validating the effectiveness of the proposed model. The validation design follows the proposed framework of the NK-Network model. First, the input module feeds the empirical project data of HZMB into the model. Second, the processing module simulates the stakeholder performance of RM in the development of HZMB by the proposed NK-Network model. Third, the output module presents the evolution graphs of RM, which reflect the varied stakeholder performance in the megaprojects.

Data input

Stakeholder–issue network in HZMB

The two-mode stakeholder–issue network reflects the complex project environment of stakeholder RM in HZMB. The sampling procedures of establishing a stakeholder-issue network are as follows. First, the official project meeting minutes are used to identify relationships between stakeholders and associated issues. The official project meeting minutes are archived by the Hong Kong Council Library, which presents a comprehensive view of stakeholder issues in every aspect of HZMB in the timeline (Xue et al., 2020b). The project meeting minutes provide objective access to show the complicated stakeholder relationships around the associated issues.

Second, the two groups of graduate students on construction project management conducted a desktop analysis to establish the two-mode stakeholder-issue networks with the collected project meeting minutes of HZMB. One group built the networks from 2003 to 2010. Another group established the networks from 2011 to 2018.

Then the two groups cross-checked the networks to ensure the accuracy of the stakeholder-issue networks in HZMB.

The detailed procedures of building a two-mode stakeholder–issue network through desktop analysis are as follows. First, the concepts of stakeholder issues are identified by conducting desktop analysis of council documents. Second, stakeholders relevant to each issue are identified when the relevant stakeholders appear in the documents regarding the same issue. Third, links are drawn to connect identified stakeholders and associated issues. For instance, the issue on the protection of Chinese White Dolphins refers to stakeholder groups, including the Coordination Group of three regional governments, the Hong Kong government, and environmental groups. Following the procedures, Figure 8 shows that the stakeholder–issue node is "the protection of Chinese White Dolphins," and three stakeholder nodes are associated with three relevant stakeholder groups. The links represent the relevance between stakeholder issues and involved stakeholders.

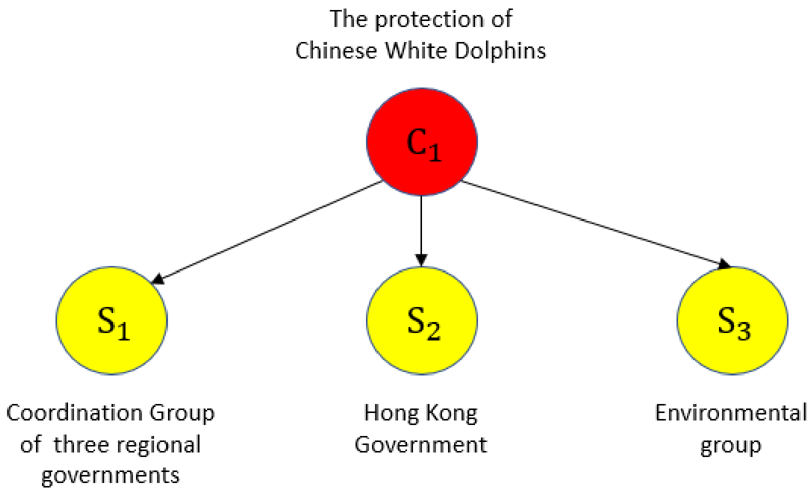


Figure 8 Example of the basic two-mode network in HZMB

The two-mode stakeholder–issue network in Figure 8 is the basic unit of the network system in HZMB, which is regarded as the basic NK model. Figure 9 shows the established annual stakeholder–issue network with timestamped documents. The number of stakeholder–issue nodes in the annual network represents the sum of basic NK models in that year. The annual network is used to calculate the stakeholder performance of RM in each time point of HZMB.

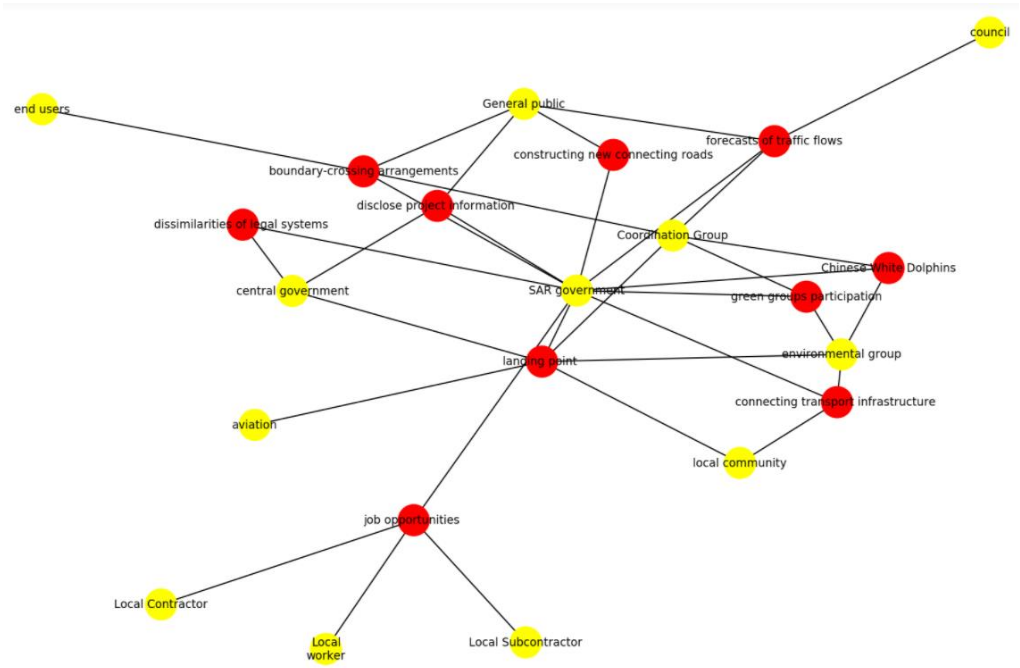


Figure 9 Example of the annual stakeholder–issue network in HZMB

Finally, 16 two-mode stakeholder–issue networks were developed from 2003 to 2018 (shown in Supplementary material S1), covering the various phases of HZMB. As stated in the section of the model design, the two-mode stakeholder–issue networks clearly depict the complex external project environment, which sets the basis for establishing the NK model to simulate dynamic stakeholder interactions on the RM of HZMB.

Performance distribution of relational strategies

The performance distribution of relational strategies shows the effect of stakeholders' internal enhancement strategy to improve the performance of RM, which faces various kinds of stakeholder issues. The previous study has measured how formal and informal relational strategies perform toward stakeholder issues that influence the corresponding project performance in 10 aspects: communication, coordination, collaboration, cost, schedule, quality, safety, labor, environment, and transparency (Xue et al., 2020a). Table 1 shows the stakeholder performance distribution based on the PLS-SEM assessment result in that research. "Ave" and "Dev" represent the mean and deviation values, respectively. With the two critical parameters, the normal distributions of stakeholder performance under formal and informal relational strategies are generated toward the issues from organizational level to project and societal level. As informal relational strategy performs insignificantly facing the issues on cost, quality, and labor, the PLS-SEM results indicate that informal relational strategy does not exert a significant effect on these issues (Xue et al., 2020a). Therefore, no general distribution scope of stakeholder performance exists under the circumstances. Therefore, the standard normal distribution is particularly set to reflect the random stakeholder performance in those conditions. As stated in the section of the model design, the influence distribution of formal and informal relational strategies is essential to generate the pay-off values for stakeholder performance on RM in the NK–Network simulative model.

Table 1 Parameters of the performance distribution of formal and informal relational strategies

	Formal Relational Strategy		Informal Relational Strategy	
Stakeholder-Issue types	Ave1	Dev1	Ave0	Dev0
communication	0.340	0.094	0.508	0.091
coordination	0.482	0.103	0.371	0.102
collaboration	0.352	0.115	0.387	0.115
schedule	0.330	0.111	0.347	0.112
cost	0.490	0.127	0.000	1.000
quality	0.509	0.096	0.000	1.000
safety	0.441	0.094	0.310	0.103
labor	0.561	0.102	0.000	1.000
environment	0.501	0.094	0.233	0.106
transparency	0.255	0.119	0.394	0.108

Data source from the literature by Xue et al. (2020a)

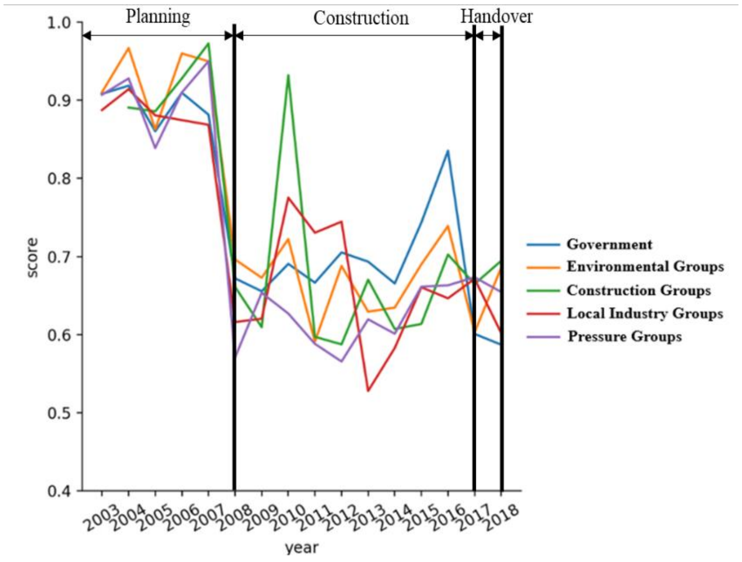
Processing

The model processing is programmed by Python 3.7. Three python libraries are adopted to simulate the stakeholder performance of RM in the megaprojects. The NetworkX library is employed to evaluate the stakeholder complexities through modeling the complicated stakeholder networks. The NK library measures the stakeholder dynamics by simulating frequent stakeholder interactions in the project. The Matplotlib library is used to visualize the model results after computation. Finally, the evolution graphs of stakeholder performance on RM are plotted as outputs for further discussion.

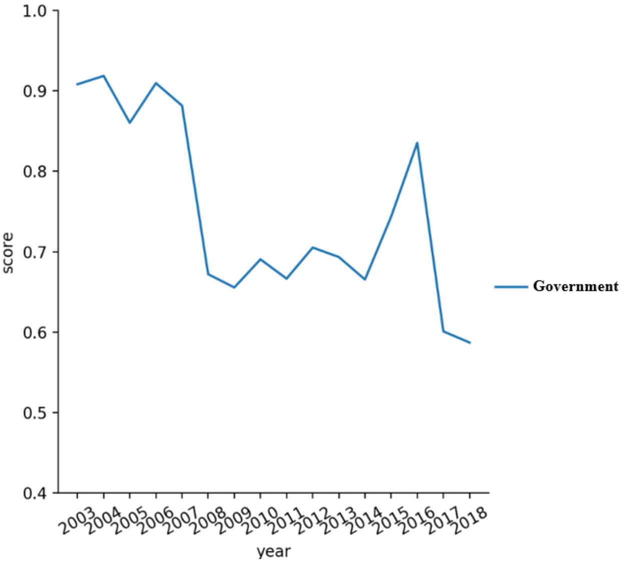
To test the model validity, five representatives of project stakeholders (profiles shown in Supplementary material S2) who were deeply involved in HZMB were invited in the input and output procedures. The stakeholders consist of five major participants, including the government, construction groups, local community, environmental groups, and local industry groups. In the input step, the representatives examined the accuracy of built-up stakeholder-issue networks and performance distributions of relational strategies. All representatives agreed that the empirical input data met the reality of the HZMB project. In the output step, the five representatives joined the workshop to examine the evolution graphs of stakeholder performance on RM. The representatives further discussed the diverse stakeholder performance of RM in the development of megaprojects. The detailed discussion is shown in the following section of Output Results.

Output results

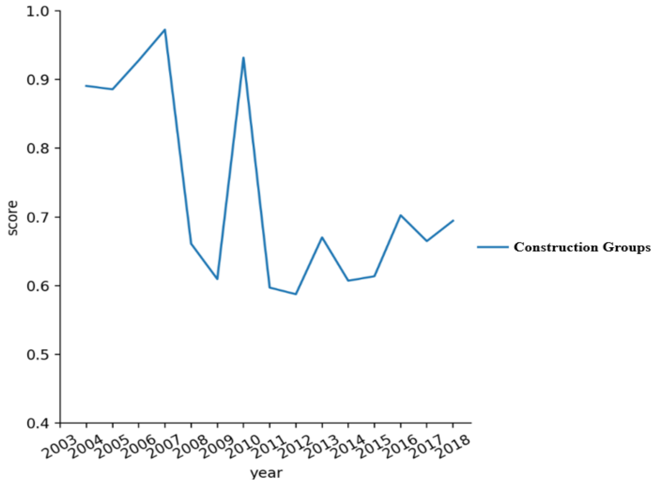
The stakeholder evolution graph (Figure 10) is useful in evaluating the trend of stakeholder performance on RM in various stages of megaprojects. As stated in the section of the model design, the evolution of stakeholder performance is helpful in revealing the weak moments of stakeholder RM in megaprojects. In the study, five stakeholder groups are analyzed with the performance evolution in the timeline, including the government, construction groups, local community groups, environmental groups, and local industry groups.



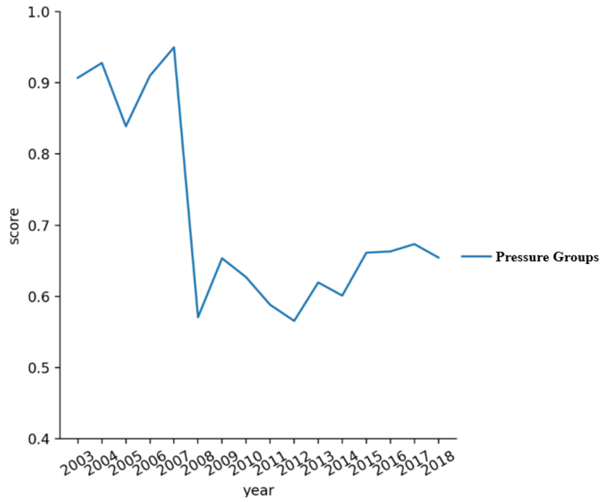
(a) All stakeholders' performance



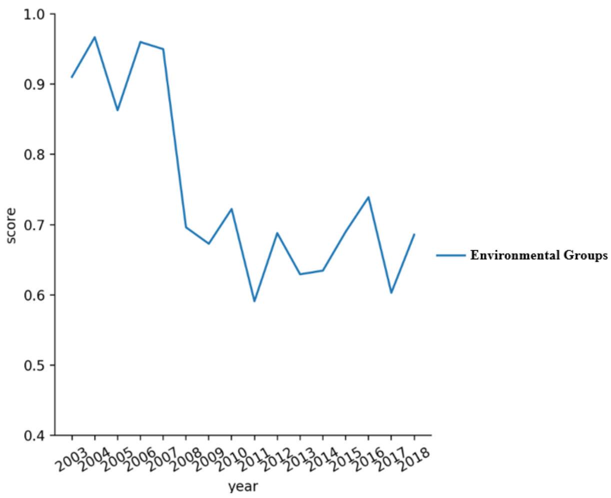
(b) Government performance



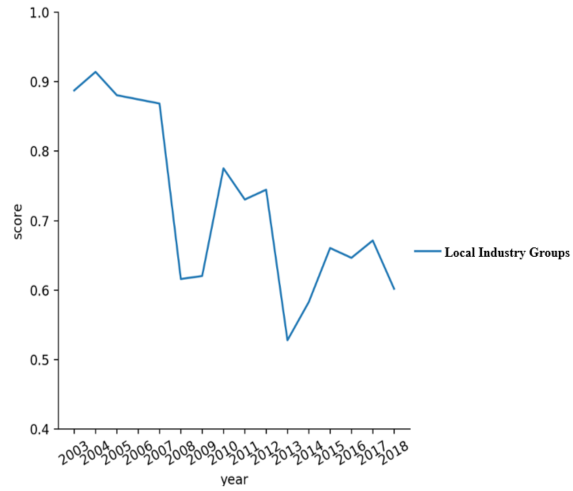
(c) Construction groups' performance



(d) Local community groups' performance



(e) Environmental groups' performance



(f) Local industry groups' performance

Figure 10 Evolution graphs of stakeholder performance on relationship management in HZMB

General patterns of stakeholder evolutions

Figure 10(a) shows the performance of RM plunged in 2008 when the project bill of HZMB was sent to the National Congress for voting. The phenomenon indicates RM of stakeholders has varying performance in the period before and after the project approval. The dramatic decrease was due to the dynamic and complex project environments at that important decision-making moment. On the one hand, as the HZMB has a large project size, there were a lot of complex project issues triggering the conflicting stakeholder interests, including financial arrangement, alignment arrangement, environmental protection, and operational management. Various project issues led to a diversity of stakeholder concerns, increasing the difficulties for RM. On the other hand, as the project feasibility study was proposed to the national congress for voting, the dynamic interactions among stakeholders occurred at that time. Since there was no room to be vague for project issues in the feasibility report, the confrontations appeared during the frequent stakeholder interactions as each stakeholder group intended to maximize its interests. The RM hardship at the critical decision-making moment is verified by interviewees. They pointed out that the RM at the decision-making moment of the project bill is challenging for stakeholders. It is likely to have an adversary social impact on the megaprojects if the stakeholder relationships cannot be managed properly at that moment, resulting in a sharp decrease in public support for the project.

Evolution of government performance

Figure 10(b) shows the evolution of government performance on RM in HZMB. The government takes a leading role in the megaprojects, as many projects are public-funded. Besides the fall of RM performance at the decision-making moment of the project bill, the government faced another big challenge of RM in 2017 when it was at the late construction stage. The RM pressure of government is agreed among interviewees.

They explained the project delay increased the complexity of the project environment at that time. As HZMB was scheduled to complete in 2016, the project postponement activated a series of conflicts among stakeholder issues in 2017, including cost-overrun, quality incidents, and safety injuries, causing difficulties in RM. Given that the government took the leading role in coordinating stakeholder relationships in the stakeholder-conflict outbreak moment, the performance score suffered from a significant plunge due to the frequent confrontations between the government and relevant stakeholders. The RM challenges at the late construction stage exert heavy pressure on the success of project completion.

Evolution of construction groups' performance

Figure 10(c) shows that the performance of construction groups had a significant decrease in 2011 when it was at the early construction stage. The construction groups play a major role in project execution under the Design and Build procurement mode, taking charge of both design and construction tasks. RM of construction groups had difficulties due to the dynamic interactions with the government, environmental groups, and local communities. The sharp reduction in 2011 was caused by conflicts on environmental issues, which led to the severe delay of project commencement. The interviewees highlighted the environmental conflict caused heavy pressure on RM of construction groups. The conflict erupted between the government and environmental groups, but it caused an economic loss of construction groups due to project delays. Construction groups had difficulty in negotiating with both sides, as the interests between the government and environmental groups were opposite (Xue et al., 2020a). After that, in the dynamic environment of the construction phase, as a major participant of construction works, the construction groups faced the challenges of various stakeholder issues (i.e., cost, schedule, quality, safety), which dragged the performance score of RM at the low level.

Evolution of local community groups' performance

Figure 10(d) shows that the performance of local community groups had a significant decrease from 2009 to 2012, when the HZMB was at the early stage. The local community group has a switched role between the proponent and opponent of the project in the complex environment. At the start of construction works, RM of local community groups was in trouble with environmental conflicts. The conflicts led to tensions between local community groups and the government. After 2012, the performance score has a steady increase since the local community groups started to handle the communication with the official departments through a constructive and peaceful approach. The local community groups learned how to convey their worries and have relevant negotiations with the government after the lessons of the fierce stakeholder conflicts in 2011. The interviewees explained that RM of Local community groups requires the kind guide by the government. Although the local communities fear the megaproject due to the environmental pollution and the disturbance of daily life, they will still support the project if their worries are seriously dealt with by the government and the foreseeable economic plan is proposed with the project development.

Evolution of environmental groups' performance

Figure 10(e) shows that the performance of environmental groups suffered three dramatic drops in 2008, 2011, and 2017, indicating the continuous RM difficulties due to the dynamic project environment. The environmental groups are the critical opposition party of the megaprojects. In the history of HZMB, the low performance was introduced by two significant conflicts at the beginning and late construction phase. The first drop in 2011 was caused by legal disputes on the environmental impact assessment report of HZMB, leading to the delay of project commencement. The dispute triggered tension between environmental groups, construction groups, and the government. The second drop in 2017 was driven by concerns about air pollution and noise caused by traffic with the completion of HZMB. This instance damaged the relationship between environmental groups, local communities, and the government. The interviewees agreed with the model results. Meanwhile, they pointed out that the RM hardship of environmental groups is likely to trigger serious conflicts around ecological protection among stakeholders, which leads to the poor cost and schedule control of megaprojects.

Evolution of local industry groups' performance

As Figure 10(f) shows, the performance of local industry groups plummeted in the mid-construction stage (2013) and handover stage (2018). Taking a role as the beneficiary of the project, the local industry groups have major concerns about the economic benefits brought by megaprojects. RM of local industry groups encounters difficulties when facing potential economic loss in the dynamic project environment. The plunge in 2013 was caused by concerns from the local industry groups on severe lag-behind local links connected with HZMB. The local logistic and tourism industries had tensions with the government and local communities on pursuing the speed-up of local connection construction to ensure their economic benefits after the completion of HZMB. The tensions caused the drop of local industry groups' performance scores on RM during the period. The other plunge was in 2018, when the HZMB was in the handover stage. The local industry groups had a wide range of discussions with the regional governments of Hong Kong, Macao, and Guangdong prior to initiating project operation. Their concerns were about how the operational arrangement of HZMB can maximize the industrious economic benefits. Hence, the heavy workload and tight schedule downgraded the RM performance of local industry groups. The model results are echoed by interviewees who warn that the RM hardship of local industry groups may downgrade their support of the project, which is harmful to obtain sufficient budget bill for the megaproject in the council.

Managerial Implications

The study provides empirical evidence on the time distribution of weak moments of RM for each stakeholder group. Table 2 summarizes the weak moments of RM in HZMB according to the results of the evolution model. The results indicate the managerial implications for project stakeholders on RM in the development of future megaprojects.

In the planning stage, the difficulties of RM widely occur among all five stakeholders, with tensions erupting, especially at the decision-making moment of the project bill. As the leader of public-funded megaprojects, the government should take responsibility to strengthen relationships among all stakeholder groups. First, the identification of long-term and short-term stakeholder benefits of megaprojects assists the government in understanding the intentions behind stakeholder behaviors. Such knowledge is useful when taking precautionary actions in RM (Zheng et al., 2017). Second, a win-win and no-blame collaborative culture is essential to be established for the government to improve stakeholder collaborations and reduce the possibility of fierce stakeholder conflicts (Suprapto et al., 2015). Third, the participation of senior executives of all relevant stakeholders in the critical decision-making moment is key to managing stakeholder relationships in a collaborative direction and maintaining effective negotiations among all parties (Zou et al., 2014). The proposed RM strategies are essential to exert a positive influence on the wide social support of the project, which is helpful for the bill approval of megaprojects.

In the early construction stage, the relationships among construction groups, local community groups, and environmental groups are most likely to be hurt due to the concerns on environmental pollutions triggered by construction works. Therefore, mutual objectives on environmental protection issues are suggested to be determined among the three parties (Meng, 2012). As a major executive of design and construction works, the construction groups are recommended to set up the acceptable goal with two major opponents (local communities and environmental groups) during environmental impact assessment and make a detailed plan to achieve environmental protection in the development of megaprojects. The action is essential to reduce risks of environmental conflicts that may lead to severe cost-overrun and time-delay of a project.

In the mid-construction stage, a joint working mechanism on economic development proposals is encouraged between local industry groups and governmental departments to maximize the economic benefits after project completion (Cheng et al., 2000). The joint work can effectively enhance RM performance for local industry groups to remove communication obstacles with the government and reinforce their working relationships. As a major beneficiary of the project, the local industry groups require a joint working mechanism with the government to address their economic concerns, which is critical to boosting their continuous support of the megaproject in the project duration.

In the late construction stage, the relationship between the government and environmental groups deserves special attention. The issue is about the pollution that may be caused by the upcoming operation of a megaproject. Thus, a fast and efficient problem-solving mechanism is critical to solving conflicts (Meng, 2012), as environmental issues are sensitive to public support toward a project. The problem-solving mechanism led by the government can quickly respond to RM difficulties by establishing a solution to remove waves of anger and worries from opponents, which is crucial for the success of project completion.

In the handover stage, open and smooth communication access is important to reduce the heavy pressures for local industry groups to manage relationships with the regional government on the operation of a megaproject (Chen and Chen, 2007). The strategy is helpful for local industry groups to have sufficient in-depth discussions with the government departments on the operational arrangement for maximizing the economic performance of the megaproject.

Table 2 Longitudinal management strategies on relationship management for stakeholder groups

Phases	Stakeholders G	C	M	E	L	Strategies
Planning	●	●	●	●	●	Accurate recognition of stakeholders' benefits; Cultivation of a collaborative culture; Participation of senior executives;
Early-construction		●	●	●		Creation of mutual objectives
Mid-construction					●	Establishment of a joint working mechanism
Late-construction	●			●		Establishment of a problem-solving mechanism
Handover					●	Open and smooth communication access

Notes:
G: Government; C: Construction group; M: Local community; E: Environmental group; L: Local industry

Conclusion

To fill the gap of lacking longitudinal stakeholder measurement of RM in megaprojects, this study proposes an NK–Network model to evaluate stakeholder evolution that considers the dynamics and complexities of megaprojects. The model is composed of three modules. The input module reflects the internal effects of RM with stakeholder-associated issues and stakeholders' relational strategies. The co-effect of the two critical factors set the basis for the evaluation of stakeholder interactions in RM. The processing module evaluates how internal effects evolve with the external environments of RM, which considers the dynamic and complex nature of megaprojects. The NK model describes the adaptive behavior of stakeholder interactions in a dynamic project environment, whereas the network model presents the complexity of stakeholders and their relevant issues in megaprojects. The integration of the two models simulates how the stakeholder performance of RM evolves under the dynamic and complex nature of megaprojects. The output module presents the evolution graph of stakeholder performance on RM in various timepoints of project duration. The evolution graph is helpful to achieve dynamic RM by revealing the weak moments of RM for each stakeholder group with providing corresponding management strategies.

Using the sixteen-year case study of the HZMB, the proposed model is proved to be effective to evaluate the evolution of stakeholder performance on RM under dynamic and complex environments of a megaproject. Moreover, the time distribution of weak moments of RM for each stakeholder is revealed, and the corresponding management strategies are proposed for achieving dynamic RM. First, there is one plunge of stakeholder performance of RM for all stakeholders in the planning stage, when the project is at the decision-making moment of bill approval. The RM hardship leads to a sharp decrease in public support for the project. Second, the weak moments of RM for five stakeholder groups are revealed. Construction, environmental, and local community groups experienced the hardship of RM on environmental protection at the start of the construction stage, which introduced the severe cost-overrun of the project. Local industry groups faced challenges in RM on economic benefits brought by the project in the middle of the construction stage, downgrading their support to obtain a sufficient budget bill of the megaproject in the council. The government suffered difficulties on RM in the late construction stage when tensions occurred due to the schedule delay, which influenced the success of project completion. In the handover stage, the RM difficulties existed for local industry groups to negotiate with regional governments on the operational arrangement, which influenced the maximization of the economic performance of the megaproject. Third, a number of management strategies are provided for stakeholders to improve RM performance in different project phases, including an accurate recognition of stakeholders' benefits, the cultivation of a collaborative culture, the participation of senior executives, the creation of mutual objectives, the establishment of a joint working and problem-solving mechanism, and open and smooth communication access.

The research makes theoretical and practical contributions. Theoretically, the study introduces the evolution modeling technique into the evaluation of stakeholder performance on RM. The simulative method successfully reveals the stakeholder evolution of RM performance in the project life cycle of megaprojects, which was previously hard to make longitudinal measurement due to the dynamic and complex environments of megaprojects. In addition, the proposed NK–Network model provides a new approach to model stakeholder dynamics and complexities in megaprojects, which is beneficial for evaluating variations of stakeholder performance in megaproject management. This model extends the current knowledge body on how to make project stakeholder analysis by modeling dynamic and complex environments of megaprojects, with bridging the knowledge domains of evolution modeling techniques and network methods. Practically, the proposed model benefits decision-makers and researchers in understanding the weak moments for stakeholders on RM in the project duration to prepare management strategies accordingly.

The proposed NK–Network model requires reliable information as inputs to make precise simulative analysis. In future studies, the official documents of multiple similar projects may be a valuable source to provide accurate information for the generation of performance distribution of stakeholder strategies and the establishment of stakeholder-associated issue networks. Therefore, an efficient text-mining approach to extract useful information from official documents relevant to various types of megaprojects will be the next step to improve the application of the proposed model.

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